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INFINITELY ADJUSTABLE ENGAGEMENT SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] This invention relates generally to systems and methods for engaging two bodies together. More particularly, the invention involves the engagement of two bodies where, during the engagement process, one of the bodies deforms the other body.

2. Description of Related Art

[0002] Clamping mechanisms are used for a variety of purposes including linear motors. One conventionally used clamping design includes locking surface teeth. While this arrangement can support large lateral forces, the distance between the teeth limits step size. Although micro-electromechanical system (MEMS) technology is helpful, teeth spacing reduction is limited, limiting step size and utility for high precision applications. Stepping speed is also significant, and ensuring proper teeth meshing for each step is often problematic, especially at high stepping frequencies. If teeth fail to mesh properly, damage and wear can occur, significantly reducing the effectiveness of a clamping device. Similarly, in gearing mechanisms, two mating gears must have correct pitch, or damage can occur. In mechanical designs, such as transmissions, two gears with dissimilar pitch often require engagement, requiring additional gears, added cost, added complexity, added weight, increased use of belts, and can cause slipping and shorten the life of gears.

[0003] U.S. patent No. 5,810,881 issued to Hoskin, et al. describes a clamping device that penetrates into a titanium nickel alloy. A shape memory alloy is described such that heating of the material causes a phase transformation. However, since heating is required, it is an inherently slow process. Such heating also requires the use of added devices, mass, adding complexity and cost.

[0004] U.S. patent No. 5,226,683 issued to Julien et al. describes a sealing gasket utilizing nickel and titanium. While deformative forces are described, recovery of the gasket upon removal of the clamping force is required. Further, a smooth surface

is desired for the seal and the surfaces that contact the seal. Also, again, heating of the seal is described.

SUMMARY OF THE INVENTION

[0005] In accordance with the present invention, systems and methods are provided for releasable engagement of two bodies. The systems include a first body that has an engagement surface that is designed for engagement with the indenter surface of the second body. As a feature of the present invention, the engagement surface of the first body is made from a pseudo-elastic material that is maintained at an "operating temperature". The operating temperature is above the martensite-austenite transition temperature of the pseudo-elastic material such that the pseudo-elastic material undergoes a conversion between the relatively hard austenite state and the relatively soft martensite state during application of stress (pressure) by the indenter. As a result, the engagement surface conforms to the indenter surface that includes one or more teeth. The penetration of the indenter teeth into the first body provides a secure and precise engagement of the two bodies.

[0006] The system includes an engagement mechanism that positions the two bodies relative to each other and provides reversible contact of the indenter surface with the engagement surface. When the indenter teeth are withdrawn from contact with the engagement surface (stress removed), the pseudo-elastic material returns to the austenite state and the engagement surface returns to its original unstressed shape. The two bodies may then be repositioned and the engagement process repeated. As a feature of the present invention, the return of the engagement surface to its original shape allows one to make extremely small movements during repositioning of the two bodies prior to re-engagement. Accordingly, the system essentially provides for an infinite degree of position adjustments.

[0007] The systems and methods of the present invention are particularly useful for engagement systems where precise positioning and/or rapid engagement and re-engagement of two bodies is required. High frequency engagement is possible because heat is not required to convert the pseudo-elastic engagement surface back to its original (non-deformed) shape. The systems and methods are well suited for use in micro systems where the indenter teeth and pseudo-elastic engagement

surfaces are extremely small and capable of positioning the two engagement bodies with precision in the sub-micron range.

[0008] In addition, the use of a pseudo-elastic material provides wear resistance that increases the life of clamping or gearing mechanisms, as compared to conventional designs. Further, the invention can be utilized in gearing systems where gears (indenters) of different pitch must interact with a single gear (engagement surface).

[0009] The above discussed and many other features and attendant advantages of the present invention will become better understood by reference to the detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIGS. 1 (A) – (C) are partially diagrammatic cross-sectional views that demonstrate the engagement of a first and second body in accordance with the present invention. FIG. 1(A) shows the initial configuration of the bodies prior to engagement. FIG. 1 (B) shows the two bodies engaged. FIG. 1(C) shows the two bodies after they have been disengaged.

[0011] FIG. 2 is a partially diagrammatic cross-sectional view illustrating an exemplary embodiment of the present invention where the indenter (second body) is surrounded by the first body (pseudo-elastic material. The two bodies are shown disengaged.

[0012] FIG. 3 is a partially diagrammatic cross-sectional view illustrating an exemplary embodiment of the present invention where the first body (pseudo-elastic material) is surrounded by the indenter (second body). The two bodies are also shown disengaged.

DETAILED DESCRIPTION OF THE INVENTION

[0013] Exemplary embodiments are described with reference to specific configurations. Those of ordinary skill in the art will appreciate that various changes and modifications can be made while remaining within the scope of the appended claims. Additionally, well-known elements, materials, devices, components,

methods, process steps and the like may not be set forth in detail in order to avoid obscuring the invention.

[0014] The systems and methods of the present invention may be used in a wide variety of applications where precise and secure engagement of two or more bodies is required. The invention may be used in connection with linear motors (stepper, DC brushed and brushless servo, inductance and AC synchronous, etc.), gearing systems, clamping systems, medical/surgical applications, dental applications, eyeglass applications, optical applications, precision placement applications and various other applications requiring fast-acting, high holding force, infinite step size resolution clamping. For example, the invention may be applied to positioning or to positioning optical systems over long travel with high resolution.

[0015] The invention is also useful in high frequency engagement-disengagement applications where high operational speeds are required. Where speed of operation is less important (i.e. optical positioning), the systems and methods of the present invention may be used to provide very small and precise changes in engagement positions. The invention is also useful in clamping systems where a fast-acting, high holding force, infinite step size resolution clamping device is required. The invention is applicable to situations and systems where one of the bodies is a drive or positioning gear. The invention provides for low-wear/long life gears with infinite pitch and an infinitely precise engagement mechanism. The invention is well suited for use in linear motors to where it provides high power density, low complexity and low cost.

[0016] An exemplary engagement system in accordance with the present invention is shown at 10 in FIG. 1 (A). The system 10 is shown in the disengaged position. The system 10 includes a first body 12 and a second body 14. The system 10 further includes an engagement mechanism that is shown diagrammatically at 16. The engagement mechanism can be any of the known mechanisms that are capable of orienting and engaging the two bodies 12 and 14 together with sufficient force to provide the desired phase change in the first body as will be described in detail below. A backing plate or substrate 13 is provided to support the first body 12, if desired. The substrate 13 is optional and may be deleted if it is not necessary or required for a particular system configuration or particular pseudo-elastic material.

[0017] The engagement mechanism 16 typically includes a control unit 18 and mechanical elements represented by lines 20 and 22 that are designed to orient the two bodies 12 and 14 relative to each other and to engage and disengage the two bodies 12 and 14 under the control of the control unit 18. Exemplary engagement mechanisms include linear step motors, clamping mechanisms and gear engagement-disengagement mechanisms, such as transmissions and drive units. The engagement mechanism can be as simple as a screw or scissors type clamp that is manually or electronically operated to engage the two bodies or it may be as complex as a multi-element engagement system, such as a precision linear step motor system that precisely engages the two bodies together at different precise locations.

[0018] The first body 12 has an engagement surface 24. The first body 12 is made from a pseudo-elastic material. Suitable pseudo-elastic materials are those that undergo a phase transition from the martensite state to the austenite state at a temperature (the A_f temperature) that is above the operating temperature of the first body 12. The "operating temperature" of the first body is the temperature at which the first body is maintained during the engagement and disengagement process. The operating temperature for the first body 12 in engagement systems in accordance with the present invention can vary from cryogenic temperatures up to 400°C and above. The operating temperature that is selected for a particular system will depend upon the A_f temperature of the particular pseudo-elastic material that is used. Operating temperatures on the order of room temperature up to 300°C are preferred.

[0019] As used herein, the term A_f refers to the temperature at which an alloy finishes transforming from the martensite state to the austenite state when the material is not under stress (i.e. at atmospheric conditions). Those skilled in the art will appreciate that when the pseudo-elastic material that makes up first body 12 is at an operating temperature that is above its A_f, applied stress lowers the elastic strain energy and induces an austenite to martensite transformation. When the stress is removed, the transformed martensite reverts back to the austenite phase, providing shape recovery. That is, the pseudoelastic material recovers its shape, not upon the application of heat, but upon a reduction of stress.

[0020] It is also known that the amount of stress that must be applied to induce the austenite to matensite transformation increases as the difference between the operating temperature and the A_f of the pseudo-elastic material increases.

Accordingly, it is preferred that the operating temperature of first body 12 be maintained within 40°C of the Af temperature for a given pseudo-elastic material during the engagement and disengagement process. It is particularly preferred that the operating temperature be within 30°C of A_f. When the operating temperature is more than 40°C above the Af, the amount of pressure (stress) that must be used to transform the pseudo-elastic material to a martensite state becomes prohibitive. In general, the stress or pressure that must be applied to achieve the transition from austenite to martensite will range from 30 mpa for operating temperatures close to A_f up to 500 mpa for operating temperatures that are closer to the preferred 40°C upper limit.

[0021] Any of the known pseudo-elastic materials may be used to form first body 12. Exemplary pseudo-elastic materials include nickel-titanium alloys, nickel-titanium-copper alloys, copper-based alloys, platinum alloys, palladium alloys, hafnium alloys, gallium alloys and cadmium alloys. Exemplary alloys include nickel-titanium-platinum, nickel-titanium-palladium, nickel-magnesium-gallium, gold-cadmium and nickel-titanium-hafnium.

[0022] Nickel-platinum alloys are preferred that contain 50 atom percent nickel and 50 atom percent titanium. Nickel-titanium alloys with other atom percentages are suitable including those that include 51 atom percent nickel and 49 atom percent titanium. A preferred operating range for nickel-titanium alloys (50/50) is from 100 to 130°C.

[0023] The engagement surface 24 may be any shape. It can be planar or non-planar. For example, the engagement surface can be arcuate, cylindrical, spherical or flat (planar). The first body 12 can also be any size or thickness. Preferably, the first body 12 will have a thickness (t) on the order of a few millimeters down to a few angstroms.

[0024] The second body 14 (also referred to as an "indenter") has an indenter surface 26 that is in the form of teeth 28. Each tooth 28 has a base 30 with a cross-sectional area and a tip 32. The shape and dimensions of the teeth 28 may vary widely depending upon the particular engagement system. The cross-sectional area of the base 30 will preferably range from a few square millimeters down to one square micron and below. The distance from the tip 32 of each tooth to the base 30 is preferably from a few millimeters to a few nanometers and below. The teeth 28 may

be in the form of ridges having a rectangular cross-section, triangular cross-section, circular cross-section, truncated triangular cross-section (as shown in FIG. 1(A)). The teeth may also be in the form of individual indenters such as pyramids, truncated pyramids, cylinders, spheres and irregular shaped protrusions.

[0025] The second body 14 is made from a material that is capable of/designed to apply force and increase stress on the pseudo-elastic material at the engagement surface 24. The indenter or second body 14 can be made from any material that is harder than the pseudo-elastic material in the martensite state. Preferably, the indenter material is also harder than the pseudo-elastic material when it is in the austenite state. Exemplary indenter materials include steel and steel alloys as well as silicon.

[0026] In FIG. 1(B), the engagement system 10 is shown in the engaged position where mechanical elements 29 and 22 have exerted enough stress (pressure), as indicated by arrowheads 21 and 23, to convert the first body 12 from an unloaded body (austenite state) as shown at 12 in FIG. 1(A) to a loaded body (martensite state) as shown at 12a in FIG. 1(B). During the engagement process, the engagement surface is converted from an unstressed shape 24 (FIG. 1(A)) to a stressed shape 24a (FIG. 1(B)). The first body 12a is sufficiently soft in the martensite state that it conforms to or matches the shape of the indenter teeth as they are pressed into the first body 12. This deformation of the unstressed engagement surface 24 to the stressed engagement surface 24a provides for a secure engagement of the two bodies.

[0027] The indenter teeth penetrate and lock into the pseudo-elastic material. This penetration into the pseudo-elastic material increases the support of lateral loads, as compared to a conventionally used material under similar stress.

[0028] FIG. 1(C) shows the engagement system after it has been disengaged from the engaged position shown in FIG. 1(B). During unloading, the indenter surface 26 and engagement surface 24 are retracted from each other (removing stress from the pseudo-elastic material). The pseudo-elastic material reverts back to an austenite phase providing shape recovery as shown at 24c. Recovery of the deformation of the pseudo-elastic material is accomplished when stress is removed, due to the composition of pseudo-elastic material. Recovery of the pseudo-elastic material occurs without heating due to the release of stress (pressure) that allows the material to revert back to the austenite state. As shown by the horizontal arrows in FIG.1(C),

the first body 12 and second body 14 may be moved relative to each other to a different position from that shown in FIG. 1(A). Since the first body 12 has returned to its original shape, the position of the two bodies relative to each other prior to re-engagement can be infinitely adjusted. As a result, the engagement mechanism 10 is capable of infinite step resolution.

[0029] The invention may be used in clamping systems where the first and second bodies are clamped together (engaged) and unclamped (disengaged) at a speed/frequency range of 0.01 to 100,000 hertz (Hz). The invention is particularly well suited for use in clamping devices that operate at high operational speeds of 10,000 Hz and above. As used herein, the operational speed refers to the loading (indenting) and unloading (removing stress). It is to be appreciated that the loading and unloading can occur repeatedly. It is also to be appreciated that between loading and unloading, indenter (second body) 14 and/or the pseudo-elastic material (first body) 12 may be repositioned. The invention may also be used for long term (quasi-static) engagement, if desired, where the operational speed approaches 0.0 Hz. In addition, the support or substrate 13 may be deleted, if necessary, in systems operating at high operational speeds.

[0030] An alternate embodiment of an engagement system in accordance with the invention is shown in partial diagrammatic form at 40 in FIG. 2. The system is shown in the disengaged position. The system 40 includes two non-planar first bodies 42 and 43 that surround a rod-shaped second body 44. The first bodies 42 and 43 each have engagement surfaces 46 and 47, respectively, that engage the indenter teeth 48. The indenter teeth 48 are in the form of triangular ridges. The first bodies 42 and 43 are made form pseudo-elastic material as previously described and the second body is made from an appropriate indenter material. The two first bodies 42 and 43 are maintained at the appropriate operating temperature for the particular pseudo-elastic material being used.

[0031] The system 40 includes a control unit 50 that operates clamping mechanisms 52 and 54 to provide clamping and unclamping of the first and second bodies as represented by arrows 56 and 58, respectively. The first body is shown as two arcuate halves that are displaced from each other a sufficient distance to allow the engagement surfaces 46 and 47 to be moved into contact with the indenter teeth. However, the first body may be in the form of a single cylindrical body that

surrounds the indenter provided that the material is sufficiently flexible to be forced into contact with the indenter. In addition, the support or substrate shown in FIG. 1 has been deleted from the embodiment shown in FIG. 2. If desired, an arcuate support for one or both of the first bodies 42 and 43 may be used.

[0032] Another alternate embodiment of an engagement system in accordance with the invention is shown in partial diagrammatic form at 60 in FIG. 3. The system 60 is also shown in the disengaged (unclamped) position. The system is the same as system 40 except that the first body 62 is rod-shaped and the second body is in the form of two arcuate clamps 64 and 65. The arcuate clamps 64 and 65 also have triangular shaped ridges 66 and 67, respectively, that function as indenter teeth. The indenter teeth are clamped down on the first body engagement surface 68 to apply the necessary stress to convert the pseudo-elastic material from austenite state to the martensite state with the resultant penetration of the teeth into the pseudo-elastic engagement surface. The clamping and unclamping of the clamps 64 and 65 is accomplished using conventional clamping mechanisms as represented by lines 70 and 72 as controlled by control unit 74. It should be noted that the entire rod 68 does not have to be made from pseudo-elastic material. It is only necessary that the engagement surface 68 include a layer of pseudo-elastic material that is sufficiently thick to accommodate the depth of penetration by the indenter teeth.

[0033] Having thus described exemplary embodiments of the present invention, it should be noted by those skilled in the art that the within disclosures are exemplary only and that various other alternatives, adaptations and modifications may be made within the scope of the present invention. Accordingly, the present invention is not limited to the above preferred embodiments and examples, but is only limited by the following claims.